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CONTENTS:

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METEOROLOGY IN THE UNIVERSITY.*

THE atmosphere presents to us a purely material and mechanical aspect, and it is this which rivets the attention of the physicist properly so-called. He views the storm thundering over his head, the floods devastating the earth, the droughts destroying the crops, the hurricane lashing the ocean, and asks, is there not order and law in the midst of this confusion? It is for such a physicist, for the meteorologist proper, for him who would understand the daily weather map and would predict the weather from day to day on a rational basis, as the engineer predicts the performance of his unbuilt engine or the chemist the behavior of some novel untried combination, that I would plead. Such a student needs a collegiate course that shall fully recognize dynamic meteorology as one of the subjects in which candidates for the degree of 'Doctor of Philosophy' may prepare for examination. Thus you will solve the problem as to what

*An extract from a report presented in 1893 to President Seth Low, of Columbia College, recommending the establishment of courses in meteorology and a meteorological laboratory in connection with the University.

Columbia College can do to provide for the meteorological needs of this country. The mere statement of these subjects—the three lines of type that show the student what he may study if he will—serves as a sufficient stimulus, if his bent is in that direction.

I maintain that there is a real demand for a broad course of instruction in meteorology and that there is an abundance of work to be done, both mathematical and experimental. The courses and the laboratory work that bear on the study of the atmosphere are almost the same as those that one would naturally take up if one were preparing to be a hydraulic engineer. The fundamental question to be resolved in the study of the mechanics of the atmosphere consists in determining what the general motions of the air must be under the influence of gravitation and the rotation of the earth; of evaporation and condensation of moisture ; of absorption and radiation of heat, and of the irregularities of oceans and continents, hills and valleys. If there were no solar heat the temperature would be fairly uniform at all altitudes, the earth and the sea would be frozen, there would be no clouds, and the atmosphere would be a stagnant layer revolving with the globe to which it adheres.

Professor William Ferrel, a native of Pennsylvania, was the first to solve approximately the equations of motion and deduce some of the phenomena which as observation shows actually exist. He proved that any free body in motion on a rotating surface would be deflected to the right in the northern hemisphere, and that a pressure in that direction would therefore accompany any effort to make the body move in a straight line. In consequence of this deflection a belt of low pressure must exist around the earth at the equator and areas of low pressure at the poles with special areas of high pressure at the tropics. Among the equations of fluid motion Ferrel included the 'equation of continuity' so-called, but found that the general solution of the problem as thus stated analytically was impracticable; he therefore took as a special solution the observed pressures and temperatures all over the globe and showed what the relative motions must be both for the lower winds and the upper atmospheric currents. He then proceeded to a discussion of the temperatures, pressures and winds that must be experienced within a region of abnormally high or low pressure, such as we now call cyclones or anticyclones. He derived the formula connecting the intensity of the barometric gradients with the winds that cut across them diagonally.

Ferrel's next memoir took up the thermodynamic problems, especially those that Espy had seen to be important factors in the development of our thunderstorms, showing that ascending air expands and by virtue of its expansion is cooled throughout its whole mass to an extent easily calculated by the laws of thermo-dynamics, and that when cooled below the dew point a formation of fog and cloud must result, giving rise to an evolution of heat and a delay in the cooling process, so that the moist air is warmer than the dry air would have been. Thus a cloud once formed becomes a center of aspiration, so that clouds and storms grow as long as they are supplied with uprising currents of moist air. Ferrel reduced to formulæ and figures the general doctrines of Espy and showed them to be perfectly applicable to a certain class of our storms, namely, those in which the ascent of air is sufficiently rapid to render the radiation of heat and the mixture with surrounding air matters of secondary importance.

The general treatise of Professor Ferrel entitled 'Recent Advances in Meteorology,' published by the Signal Office in 1885, gives most of his earlier results with many revisions and new ideas.

Very similar results were published by Oberbeck in 1882 and 1888, employing more elegant mathematical methods and advancing a step beyond Ferrel's first publications. It may, however, be stated that the general solution of the hydro-dynamic equations presupposes a definite knowledge of the distribution of temperature or of density in the atmosphere; and, of course, the solutions given by Oberbeck and Ferrel are intended to apply only to the atmosphere as we observe it.

The thermo-dynamic phenomena attending the ascent and descent of the air have been treated analytically by many authors, such as Sir William Thomson, Reye, Chambers, Hann, Guldberg and Mohn; within the last few years this subject has been worked out in a very elegant, graphic way by Herz and von Bezold.

The memoir of Herz considers only adiabatic changes, while the memoir of Bezold considers the changes that are not strictly adiabatic. It is evident on a slight consideration that the quantity of heat within a given mass of air is continually changing by reason of several processes: *First*, the direct absorption from the sun; *second*, radiation to colder objects; *third*, the loss by convection of heat attending the precipitation of rain or snow; *fourth*, the gain by convection attending evaporation from the earth into the air; *fifth*, the process of mixture that is constantly going on. Therefore atmospheric processes are by no means always adiabatic, and Bezold's graphic methods enable us quickly to solve any problem that may be presented. Bezold and Helmholtz have agreed in adopting and recommending the term 'potential temperature' as defining the temperature that a mass of gas would have if brought to a normal pressure, without loss or gain of heat.

Helmholtz added to our knowledge of atmospheric movements by his studies on the conditions of stability among masses of air that have a discontinuous motion, such as two vortex rings encircling the earth in different latitudes and having different temperatures. In general, stable equilibrium is possible only when the warm ring is on the polar side of the cold ring.

A pupil of Helmholtz, Professor Diro Kitao, of the Imperial Academy of Agriculture of the University of Tokio, has made an elaborate study of the forms of motion that attend the meeting of two horizontal currents, which then pile up and roll back on themselves.

Finally, Helmholtz has given us very remarkable memoirs on waves in the atmosphere and the distribution of energy in the winds and the ocean waves. Moeller, Sprung, Hann, Wien and others have elaborated the ideas thus contributed.

The so-called 'convection theory of storms' that we call Espy's assumes that the latent heat of vapor is the maintaining power and that the original ascent of the moist, warm air is due to its buoyancy. Therefore we could have no continued cyclonic motion without ascending moisture and clouds and rain. But the other studies have, I think, put it beyond doubt that there is another equally important cause at work, which undoubtedly is the fact that the upper air flowing northward from the equator as a return trade is slowly cooling by radiation and descending. It eventually reaches the earth here and there in spots which are small areas of clear sky in the tropical regions, but are large areas of cold dry air and high pressure in northern latitudes. If the air is cooled by radiation faster than it is warmed up by the compression attending its slow descent, then it descends as clear, cold and dry air, and only after reaching the earth's surface does it begin to warm up again in the daytime faster than it can cool at night. As this dry cold air under-runs the moist, warm air at the

earth's surface, or as two areas of high pressure flowing toward each other must lift up the lighter air between them and set it into cyclonic rotation, we must, therefore, recognize the general conclusion that Espy's aspiration cyclone as developed by Ferrel is not the only form of cyclone, but that those due to descending cold air and, therefore, having the general circulation of the atmosphere as their fundamental cause are equally entitled to consideration.

To this last and latest development from the theoretical side I need only add that the study of the motions of the clouds has enabled me to assert confidently that there is no form of motion known to the student of the mechanics of fluids but what is to be found beautifully illustrated in some important phenomenon of the atmosphere. I may give one illustration of this statement.

All have seen the beautiful standing waves on the surface of a little stream of water flowing over a rocky bed. The theoretical study of these waves began with Bidone early in this century and has been especially prosecuted by Bazin and Boussinesq in France and Sir William Thomson in Scotland. Precisely similar waves must occur in the atmosphere, but can only become visible to us by the formation of clouds at the summit of each wave if the air rises high enough. Invisible standing waves exist over our heads all the time. It was my good fortune to make an extensive series of observations on a remarkably well developed system of standing waves capped by clouds, which perpetually extend from the summit of Green Mountain, on the Island of Ascension, to the leeward for a hundred miles under the influence of the steady southeast trade wind. These become invisible when the air becomes a little cooler or dryer, and consequently they actually disappear every night only to reappear as regularly every day.

But I need not dwell any longer on the relations of the theoretical and the actually observed motions of the atmosphere. Our interest in the meteorological or dynamical theories and their application to the atmosphere is not inferior to our interest in any other physical science.

The possibility of making accurate long-range predictions of the weather and the seasons is recognized as an ultimatum that should fire the zeal of every young physicist.

Meteorology has advanced far beyond the stages of observation and generalization. It has had its Newton, Laplace, Dove, Espy, Forrel, Oberbeck, and Helmholtz and Thomson. As an application of mathematical physics it outranks all other branches of science in its universal importance and its difficulty. Why should it not be recognized as worthy of study in our universities?

COURSE OF INSTRUCTION IN METEOROLOGY.

The following courses in the Department of Meteorology are designed to give a complete review of the present condition of that science, and are therefore necessarily extended through four years ; but the series of lectures is so arranged that each of the four divisions is complete within itself; each course presents a view of a branch of the subject such as may be desired by a large number of students who need this information in connection with other branches of knowledge to which they are specially devoting themselves.

Students who intend to take the degree of Ph. D. in meteorology, and who therefore make this the major subject in connection with several other minor courses, must pursue the whole four years' course. Those who merely desire to understand observational meteorology will probably find the first year's course sufficient. Those who desire to do original work in climatological study should also take the second year.

The third year's course is designed for those who wish to perfect themselves in methods of making local weather forecasts. Finally, the fourth year's course summarizes the present state of our knowledge of the mechanics and physics of the atmosphere.

FIRST YEAR.—Observational Meteorology. The methods of observation; the simpler instruments, their errors, corrections and reductions; the theory and use of self-registers; the forms of record and computation; personal diary of the weather.

Time.—About eighty lectures, or two hours a week, as also eighty other hours of personal investigation of instruments and their exposure.

Concomitant Studies.—Algebra and trigonometry are the necessary preliminaries to this course. Elementary laboratory physics, as illustrated by Hall and Berger's text-book, is desirable as a preliminary, but may be pursued as a concomitant study. The German language is earnestly recommended as a concomitant. The differential and integral calculus should be studied as preliminary to the fourth year.

SECOND YEAR.—Climatology, both local and general; statistical meteorology, generalizations, averages, periodicities, irregularities. The relations of climate to geology, to vegetation, to animal life, and to anthropology.

Time.—About forty lectures and four hours weekly given to the investigation of special problems proposed in each lecture.

Concomitant Studies.—Students should familiarize themselves with the use of logarithms; the method of least squares; the laws of chance; the details of physical geography, orography, geology and ocean currents; the physiology of plants and animals; the distribution of species; physical astronomy, especially that of the earth, sun and moon; terrestrial magnetism; the chemistry of the atmosphere; the biology of atmospheric dust. Physical laboratory work on radiation, conduction and absorption of heat, on the condensation and evaporation of vapor, and on elementary electricity, is recommended. The study of German, the calculus and analytic mechanics should be continued as preliminary to the remainder of the Course.

THIRD YEAR.—Practical Meteorology; the daily weather chart; the empiric laws of weather changes as dependent on meteorological data and on the arrangement of continents, plateaus, mountains, oceans, etc.; weather types and typical weather charts; predictions of daily weather storms and general predictions of seasonal climates; verification of predictions.

Time.—About forty lectures and about five hours a week additional in verifying predictions.

Concomitant Studies.—Methods of chart projection; experimental laboratory work in both steady and discontinuous motions of fluids and gases; mathematical and experimental electricity; the laws of refraction and interference of light; elementary hydrodynamics and thermo-dynamics; differential equations and definite integrals; the German language.

FOURTH YEAR.—Theoretical Meteorology. Insolation. The absorption, conduction and radiation of heat by the air and by the earth. The thermo-dynamics and physics of the atmosphere; the graphic methods of Herz and Bezold. Convective equilibrium, as applied to the atmosphere of the sun by Lane, and to that of the earth by Sir William Thomson (Lord Kelvin), and their successors. Motion on a rotating globe; Ferrel's and other simple approximate relations between baric gradients and the wind and temperature; Ferrel's general circulation of the atmosphere and his cyclones and pericyclones and tornadoes. Galton's cyclone and anti-cyclone. Fourier's most general equations of gaseous motions.

Oberbeck's general circulation. Helmholtz' horizontal rolls. The investigations of Diro Kitao, Guldberg and Mohn, Marchi, Boussinesq, A. Poincaré, Sprung, Siemens, Moeller, Ekholm, Ritter, Lindeloff, Margules and Hermann into the motions of the atmosphere. Viscosity and discontinuity. The possible special solutions of the general equations of fluid motions that apply to the true atmospheric circulation, both on the earth and on the other planets. Atmospheric tides ; theories of Laplace, Ferrel, Rayleigh, Margules, A. Poincaré. Theories of atmospheric electricity.

Time.—Eighty lectures and an additional four hours a week given to special reading and investigation and to the preparation of the final thesis, as closing the four years' course.

Concomitant Studies.—Riemann's *Differential Gleichungen :* Auerbach's *Hydrodynamics ;* Lamb's *Hydrodynamics* (new edition); physical laboratory work in gaseous motions, optical and electrical phenomena.

THE METEOROLOGICAL LABORATORY.

In order to carry out an ideal course in meteorology it is necessary to not merely study lectures and text-books but the current daily weather maps; to practice the use of instruments and to keep weather records; to investigate special questions in local climatology, and to personally explore the atmosphere.

In the meteorological laboratory the student should investigate experimentally questions that arise in relation to the motions of the atmosphere, which includes almost every pertinent form of experiment in the motions of fluids and gases. Provision should also be made for the study of such optical phenomena of the atmosphere as refraction, absorption, interference, scintillation, mirage, and sunset colors.

This laboratory should also provide for study and practice with self-registers, the study of the thermo-dynamics of the air and aqueous vapor; the determination of the amount of heat received from the sun; the continuous records of atmospheric electricity, terrestrial magnetism, earth currents, the tides and earthquakes.

The laboratory should also provide mathematical apparatus or mechanical devices by which complex questions in the motion of the atmosphere may be solved.

Facilities should be given for the study of atmospheric dust, especially in its relation to the temperature of the air and to the formation of clouds and rain.

The laboratory should contain a working library and bibliography.

CLEVELAND ABBE.

WASHINGTON, D. C.

GEOLOGIC ATLAS OF THE UNITED STATES.

FOLIO 1, LIVINGSTON, MONTANA, 1894.

THIS folio consists of $3\frac{1}{4}$ pages of text, a topographic sheet (scale 1:250,000), a sheet of areal geology, one of economic geology, one of structure sections, and one of giving a columnar section. The text is signed by Joseph P. Iddings and Walter H. Weed, geologists, and Arnold Hague, geologist in charge.

The area of country covered by the folio lies between the parallels of latitude 45 and 46 and the meridians 110 and 111, and embraces 3,340 square miles. It is within the State of Montana, including portions of Gallatin and Park counties, and the town of Livingston is within its limits. The region is elevated, the lowest point being over 4,000 feet, the major portion over 6,000 feet, and the highest peaks over 11,000 feet above sea level.

The principal topographic features are the Snowy Mountains, Gallatin Range, Bridger Range, Crazy Mountains and Yellowstone Valley. The Yellowstone River is the main drainage channel for the area. It enters the district from the Yellowstone